MECHANICAL ARM AND COUNTERBALANCE ASSEMBLY

BACKGROUND

1. Field of the Present Invention

The present invention is in the field of mechanical devices and more particularly in the field of counterbalanced mechanical arms or extension.

2. History of Related Art

In the field of mechanical systems, mechanisms for counterbalancing a rotating or pivoting arm are found in a wide variety of applications from construction equipment to computer displays. Referring to FIG 1, an illustration of fundamental counterbalancing concepts is presented. In FIG 1, a mechanical member or arm **102** is fixed to a pivot point **104**. The pivot point **104** is used to define the origin of a Cartesian coordinate system that defines the plane within which mechanical arm **102** is free to rotate. In this illustration, the force of gravity (g) is shown as a vector pointing in the -y direction. For purposes of determining the movement or torque exerted about the pivot point **104** by mechanical arm **102**, the arm can be represented as a point mass **106** having a weight of W and positioned at a distance of r_1 from pivot point **104**. Mechanical arm **102** is free to pivot about pivot point **104**. The position of mechanical arm **104** is described by the angle ϕ. Quantitatively, the movement exerted on the pivot point **104** by arm **102** is $r_1*\cos(\phi)*W$.

Counterbalancing mechanical arm **102** is achieved in FIG 1 by providing a counterbalance weight **112** and a counterbalance extension **110** that extends from pivot point **104** collinear with arm **102**. Counterbalance weight **112** has a weight C and is located a distance r_2 from pivot point **104**. Counterbalancing is achieved when the movement exerted about pivot point **104** is equal in magnitude and opposite in direction from the movement exerted by mechanical arm **102**. Quantitatively, this state is achieved when $r_2\cos(\phi)C=r_1\cos(\phi)W$ or $r_2C=r_1W$. Unfortunately achieving this type of counterbalancing requires the addition of an undesirably long extension piece **110**, undesirable additional weight C, or both.

An attempt to address the undesirable weight and size of the counterbalance approach of FIG 1 is illustrated in FIG 2. In this counterbalance system, a torsional spring **120** is attached to

mechanical arm **102** to produce a counteractive movement on mechanical arm **102**. This approach limits the arc in which mechanical arm **102** is free to move and may be balanced in just one or two locations as the force exerted by spring **120** varies with the position of the arm. Another commonly encountered configuration, as depicted in FIG 3, employs a linear spring **130** connected between an extension piece **132** of arm **102** and a fixed point to produce a force on the arm. This approach also undesirably limits the movement of mechanical arm **102** and produces a force that only counterbalances the mechanical arm in just one or two positions. It would be desirable to implement a mechanism and assembly that would enable the counterbalancing of a mechanical arm. It would be further desirable if the implemented mechanism permitted complete freedom of movement of the mechanical arm. It would be still further desirable if the implemented solution was statically balanced independent of the position of the mechanical arm.

SUMMARY OF THE INVENTION

The objectives identified above are achieved by a counterbalancing assembly according to the present invention. The assembly includes a mechanical arm connected to a fixed point about which the arm can pivot. A first end of a counterbalance link is also pivotally connected to the pivot point while a second end of the counterbalance link includes a pin. The counterbalance pin engages a first slot in a yoke device. The first slot is oriented in a first direction, which is typically either horizontal (0°) or vertical (90°). The yoke device includes second and third slots oriented perpendicularly with respect to the first slot. The second and third slots engage fixed position pins that restrict the motion of the yoke mechanism. The counterbalance pin is connected to a first end of a force generating apparatus such as a spring. The spring is preferably a constant force spring that produces a force that is substantially independent of the spring's displacement. A second end of the force generating apparatus is connected to the yoke wherein the force generating mechanism is oriented in the direction of the first slot. The yoke slots, in conjunction with the constant force spring, produce a force on the counterbalance pin that does not vary, in magnitude or direction, with the rotational position of the counterbalance extension. By adjusting the dimensions of the counterbalance extension and the force produced by the force generating apparatus, the assembly produces a torque or movement on the pivot point that counteracts the movement produced by the force of gravity acting on the mechanical arm

regardless of the rotational position of the mechanical arm. The mechanical arm and counterbalance link may be collinear or perpendicular to each other depending upon the implementation. Additional mechanical arm and counterbalance extension links may be connected to the first mechanical arm to produce a multi-segmented or articulated mechanical structure that remains statically balanced independent of the rotational position of any of the mechanical arm segments. In one embodiment, the counterbalanced, multi-segment structure is achieved with a single spring.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects and advantages of the invention will become apparent upon reading the following detailed description and upon reference to the accompanying drawings in which:

FIG 1 is a conceptual illustration of static balance achieved using a counterbalance weight;

FIG 2 illustrates a torsional spring counterbalance assembly according to the prior art;

FIG 3 illustrates a linear spring counterbalance assembly according to the prior art;

FIG 4A illustrates selected elements of a counterbalance assembly according to one embodiment of the invention;

FIG 4B is a graphical illustration of the prevailing forces in the assembly of FIG 4A;

FIG 5A illustrates selected elements of a counterbalance assembly according to a second embodiment of the invention;

FIG 5B is a graphical illustration of the prevailing forces in the assembly of FIG 5B;

FIG 6 is a detailed side view of the assembly of FIG 4A or 5A;

FIG 7 is a conceptual illustration of a multi-segment embodiment of the invention.

While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof are shown by way of example in the drawings and will herein be described in detail. It should be understood, however, that the drawings and detailed description presented herein are not intended to limit the invention to the particular embodiment disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the present invention as defined by the appended claims.

DETAILED DESCRIPTION OF THE INVENTION

Generally speaking, the present invention contemplates a mechanism that provides a substantially constant counterbalancing torque to a mechanical arm free to pivot about a pivot point. A counterbalancing extension link is connected to the pivot point. The orientation of the mechanical arm to the extension link is fixed. A force that is substantially constant in both magnitude and direction is applied to the free end of the extension link. The force is substantially invariant with the rotational positions of the extension link and mechanical arm. The magnitude of the constant force is determined by the length of the extension link and the torque on the pivot pin attributable to the mechanical arm to produce a counterbalancing torque on the pivot pin that maintains the mechanical arm in a state of static equilibrium without restricting the arc in which the arm is free to move.

Referring now to FIGs 4A and 4B, a counterbalance assembly **140** according to one embodiment of the invention is depicted. In the depicted embodiment, counterbalance assembly includes a mechanical arm **142** attached to and free to rotate about a pivot point **144**. In the orientation of FIG 4A, the force of gravity has a downward direction. Assembly **140** further includes a counterbalance extension link **146** that is also connected to pivot point **144**. Extension link **146** and mechanical arm **142** as depicted in FIG 4A are collinear such that, as observed in the view of FIG 4A, mechanical arm **142** and extension link **146** form a straight line.

The assembly **140** as depicted further includes a yoke **150** that includes a first slot **152** having a vertical orientation. A pin **154** affixed to a free end of extension link **146** is engaged or otherwise located within first slot **152**. The pin **154** is free to move within slot **152** as the mechanical arm is rotated about pivot point **144**.

Yoke **150** is constrained to move in a single direction, which is perpendicular to the orientation of first slot **152** as the link pin **154** rotates about pivot point **144**. In the depicted embodiment, yoke **150** is constrained to move in the +/- x-direction by first and second constraining pins **160** and **162** which attach to a fixed reference **165** through second and third slots **164** and **166**, respectively, in yoke **150**. In this embodiment, the position in the x-direction of yoke **150** tracks the x-direction position of link pin **154** as it rotates about pivot point **144**. As depicted in FIG 4A, slots **164** and **166** are oriented perpendicular to first slot **152**. In other embodiments, the means for constraining the movement of yoke **150** may include, for example, a

bearing and track assembly (not shown) in which a fixed position track constrains the direction of motion for yoke **150**. Yoke **150** is displaced from the underlying fixed reference **165** by a set of spacer devices (not shown).

As shown in the side view detail of FIG 6, mechanical arm **142** is preferably positioned on the first side of fixed reference **165** while extension link **146** and yoke **150** are positioned on the other side. In this configuration, mechanical arm **142** is free to rotate through a full 360° arc without interference. FIG 6 also illustrates a pin **168** that links mechanical arm **142** and extension link **146**. In the preferred embodiment, mechanical arm **142** and extension link **146** are rigidly affixed to linking pin **168** such that the angle defined by mechanical arm **142** and extension link **146** is constant. Linking pin **168** is free to rotate within a hole in fixed reference **165** in which the pin is engaged.

Returning to FIGs 4A and 4B, assembly **140** includes a force generating device **170** connected between the extension link pin **154** and a fixed pin **172** in yoke **150**. In the depicted embodiment, force generating device **170** is oriented to exert a downward force on extension link pin **154**. It will be appreciated that, as mechanical arm **142** is rotated about pivot point **144**, extension link pin **154** also rotates about the pivot. As extension link pin **154** rotates about the pivot, yoke **150** translates in the +/- x-direction (horizontally) to maintain the position of yoke pin **172** directly below the extension link pin **154** and thereby maintain the orientation of force generating device **170**. In this manner, yoke **150** maintains the direction of the force exerted by force generating device **170** in a constant direction such that the direction of the force is independent of the rotational position or angle of mechanical arm **142** or extension link **146**.

In the preferred embodiment, force generating device **170** is implemented with a constant force spring. As its name implies, a constant force spring is a device that exerts a force that is substantially invariant with spring displacement, at least within a specified range of displacement. If such a constant force spring is constrained by the implementation to maintain its displacement within the substantially constant force range, the corresponding force generating device may be characterized as a constant force generating device.

The combination of the constant force device **170** and the yoke **150**, which provides a constant direction mechanism, it will be appreciated that assembly **140** maintains a force on extension pin **154** that is constant in both magnitude and direction. The force of gravity, likewise, provides a constant force on a center of mass **143** of arm **142**. These two forces

produce countervailing torques about pivot point **144**. By manipulating the value of force generated by constant force spring **170** and the dimension (length) of counterbalance extension link **146**, the torque attributable to counterbalance extension link **146** and the torque attributable to the force of gravity acting on arm **142** may be made to be equal in magnitude and opposite in direction such that the two forces counterbalance each other such that the mechanical arm is in static equilibrium.

Referring to FIG 4B, the relevant forces at work in assembly **140** are graphically illustrated to emphasize that the static equilibrium condition described above is not dependent upon the rotational position of the mechanical arm. With mechanical arm **142** forming the angle ϕ with respect to the x-axis and the mechanical arm's center of mass point **143** being located a distance r_1 from the pivot point **144**, it can be trivially determined that the movement about pivot point **144** caused by mechanical arm **142** is $r_1*\cos(\phi)*W$. Similarly, it can be readily shown that collinear counterbalance extension link **146** forms the angle ϕ with the x-axis and that the movement about pivot point **144** caused by the action of force generating device **170** on counterbalance extension link pin **154** is $r_2*\cos(\phi)F$ where r_2 is the length of counterbalance extension link **146** and F is the magnitude of the force created by force generating device **170** (ignoring as inconsequential, or perhaps adjusting for the weight of counterbalance extension link **146** itself). The sum of torques is thus equal to $r_1*\cos(\phi)W-r_2*\cos(\phi)F$ and equilibrium is achieved by setting $r_2F=r_1W$. The most significant feature regarding this equality is the absence of the rotational angle ϕ. Thus, the equality is true for any value of ϕ (i.e., any position of the arm). Thus, assembly **140** as depicted in FIG 4A, includes a yoke **150** that enables a force producing device to apply a force that is constant in magnitude and direction to a point that is rotating about a pivot point.

The force generating device **170** may be implemented with a constant force spring as described above. In one embodiment, the constant force spring includes a long and thin rectangular steel strip rolled to form a hollow cylinder. One end of the cylinder is rigidly attached to the yoke pin while the coiled end is loosely centered around an extension of the link pin **154**. In other embodiments, force generating device **170** may be implemented with a tension spring, pneumatic cylinder, or other suitable means for providing a constant force.

Referring now to FIG 5A and 5B, a second embodiment of assembly **140** is depicted. In this embodiment, the mechanical arm **142** and counterbalance extension link **146** are

perpendicular to each other. This embodiment may be beneficial in reducing the total space required to implement the assembly or to provide flexibility to the design of a mechanical system that employs assembly **140**. In any event the perpendicular orientation of counterbalance extension link **146** and mechanical arm **142** necessitates changes to the configuration of yoke **150**. Specifically, as depicted in FIG 5A, the depicted embodiment of yoke **150** includes a first slot **152** that is oriented perpendicular to the force of gravity as it acts on mechanical arm **142**. Similarly force generating device **170** is connected between counterbalance extension link pin **154** and a yoke pin **172** and oriented to apply a horizontal force to counterbalance extension link pin **154**. The second and third slots **164** and **166** of yoke **150** as depicted in FIG 5A enable the yoke to translate in a vertical direction as mechanical arm **142** rotates about pivot point **144**.

Referring to FIG 5B, the graphical representation of the forces acting on the assembly show that the movements about pivot point **144** are $r_1*\cos(\phi)*W$ and $r_2*\cos(\phi)*F$, where F is the horizontally oriented force exerted on counterbalance extension link pin **154** by horizontally oriented force generating device **170**. It will be observed that these equations are the same equations that applied to the collinear embodiment depicted in FIG 4A. Thus, by altering the orientation of the force generating device **170** to coincide with the change in mechanical arm configuration, the same result (i.e., static equilibrium for all ϕ from 0° to 360°) is achieved.

In FIG 7, a multiple-segment embodiment of assembly **140** is depicted to emphasize a scalable implementation of the present invention. In the multiple segment embodiment, two or more assemblies mechanical arms **142A** and **142B** are linked, with the pivot point **144B** of second arm **142B** being located on first arm **142A** and so forth. Yokes **150A** and **150B** are used to maintain constant force on link pins **154A** and **154B** respectively in conjunction with a constant force mechanism. In some embodiments, each segment has its own constant force device such as the constant force spring described above. In the depicted embodiment, a counterbalanced multi-segment structure **140** is achieved using a single spring **171** connected to link pins **154A** and **154B** via fixed pins **172A** and **172B**. In this case, the single spring **171** applied the same constant force to link pins **154A** and **154B**. By adjusting the length of extension links **146A** and **146B** (i.e., the length of the corresponding r_2 values), the movements about pivot points **144A** and **144B** can be adjusted to counter balance the mechanical arms **142A** and **142B**. With each segment in static equilibrium about its corresponding pivot point, the

entire structure is in static equilibrium about the original pivot point without regard to the rotational angle of any of the corresponding segments.

It will be apparent to those skilled in the art having the benefit of this disclosure that the present invention contemplates a counterbalanced arm mechanism. It is understood that the form of the invention shown and described in the detailed description and the drawings are to be taken merely as presently preferred examples. It is intended that the following claims be interpreted broadly to embrace all the variations of the preferred embodiments disclosed.